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UPDATE

Study of normative values of the fusional amplitudes of ocular convergence and divergence

Estudo dos valores normativos das amplitudes fusionais de convergência e divergência oculares

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KEYWORDS:
Orthoptics; Astenopia; Ocular convergence; Binocular vision.

ABSTRACT
This article seeks to start the determination of paw normative values the oculomotor behavior in disjunctive movements of convergence and divergence near and far in trying to guide the clinical activities of orthoptics and ophthalmology.

PALAVRAS-CHAVE:
Ortóptica; Astenopia; Convergência ocular; Visão binocular.

RESUMO
Esse artigo busca iniciar a determinação de valores normativos para o comportamento oculomotor nos movimentos disjuntivos de convergência e divergência, para perto e para longe, na tentativa de nortear a avaliação ortóptica e os exercícios ortópticos.

INTRODUCTION

The reference values of the fusional amplitudes to evaluate extrinsic ocular motility have become a topic of discussion in recent years owing to the lack of updated scientific research. Most studies in which normality values have been presented were conducted in the 1980s when visual demand, mainly for the near range, was much lower than the current one[1-2].

It is empirically observed that visual stimuli, especially that of near vision, occur earlier in recent generations owing to the use of computers, video games, and mobile phones, along with the literacy process initiating earlier. Based on empirical observations, we question whether the reference values of vergence amplitude used by orthoptic consultants would require updates. Additionally, we noted that even the regularly used values do not have updated studies conducted on them.

Vergential movements, or vergences, are binocular, coordinated, and disjunctive eye movements in the same path but opposite directions, which seek to adapt their relative parallel position to allow images located at different distances of the individual to stimulate binocularly corresponding retinal areas, making sensorial fusion of the image possible.

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Eye movements for fusional convergence are the broadest, wherein values of ≥30$^{\Delta}$ are commonly found. Conversely, eye movements of fusional divergence are smaller, reaching values of up to 8$^{\Delta}$[3]. These eye movements can relatively vary among people, but through orthoptic exercises, they can be modified with respect to their amplitude and stability[4].

Duane[5] measured the amplitude of vergential movements in a group of normal subjects aged 16–40 years. In 60% subjects, fusional amplitude of convergence ranged between 38$^{\Delta}$ (minimum) and 51$^{\Delta}$ (maximum). However, there is lack of information on the measurement characteristics. Thus, based on the values presented in this classic study[5], the most likely hypothesis is that these were measurements performed for near visual fixation. The authors also concluded that age has little effect on the fusional amplitude and that frequent eye activity through orthoptic exercises is the most important factor.

Joyce Mein[6] considers normality values of 15$^{\Delta}$/15$^{\Delta}$ for distant convergence amplitudes (fusional and refusional breaking values) and 35$^{\Delta}$–40$^{\Delta}$ for near convergence. Values for distant divergence were 5$^{\Delta}$–7$^{\Delta}$ and those for near divergence were 15$^{\Delta}$–15$^{\Delta}$; the authors did not describe the evaluation method used. Burian[7] only referred to distant amplitudes, considering 20$^{\Delta}$/20$^{\Delta}$ for convergence and 6$^{\Delta}$–8$^{\Delta}$ for divergence, without mentioning the method applied.

The authors of Monteiro's chapter[8], the study with a more complete description of convergence amplitudes, found distant values of 20$^{\Delta}$–25$^{\Delta}$ and near ones of 30$^{\Delta}$–35$^{\Delta}$, as evaluated using the prism bar.

These values are presented in table 1, in which the first and second values cannot be mistaken with breaking/refusion because there is no clarity in the description of the methods used.

The discrepancy of normative values found in the literature[5-7], along with the lack of recent studies with appropriate description of the equipment and procedures used, always hindered the classification of vergential, normal, and reduced amplitudes as well as the diagnosis of patients with disturbed binocular vision or convergence insufficiency. Moreover, changes in current visual behaviors requiring a greater demand for binocular movements from an early age have motivated the present study.

Thus, we aimed to determine normative values for the oculomotor behavior of the fusional amplitudes of convergence and divergence for activities conducted at a distance (5m) and near (33cm) in subjects living in the city of São Paulo, Brazil.

Table 1. Normative values for breakdown/refusion available scientific publications

	Convergence near (0.33m)	Convergence far (5.0m)	Divergence near	Divergence far
Bicas H., 2014[3]	30$^{\Delta}$		8$^{\Delta}$	
Duane, A., 1933[5]	38$^{\Delta}$ to 51$^{\Delta}$			
Mein, J., 1986[6]	35$^{\Delta}$ to 40$^{\Delta}$	15$^{\Delta}$/15$^{\Delta}$	15$^{\Delta}$/15$^{\Delta}$	05$^{\Delta}$ to 07$^{\Delta}$
Burian, H., 1985[7]		20$^{\Delta}$/20$^{\Delta}$		06$^{\Delta}$ to 08$^{\Delta}$
Monteiro, K., 1998[8]	30$^{\Delta}$ to 35$^{\Delta}$	20$^{\Delta}$ a 25$^{\Delta}$		

METHODS

We selected 35 subjects, 24 females and 11 males, aged 4–39 years (mean 15.2 years; SD=9.9; median=11 years). The sample size was determined by considering mean values from the literature for a sample power of 0.80 and a significance level of 0.05.

The inclusion criteria were as follows: asymptomatic individuals[9], distant visual acuity of recognition (optotypes) of 1.0 (Snellen decimal) or better in both eyes, near visual acuity of recognition J1 (Jaeger) measured at 0.37m in both eyes, always with the best refraction optical correction (considered to be emmetropia if up to 1.50 SPH and/or 1.00 CYL); orthophoria or low phoria (near exophoria up to 4$^{\Delta}$ and distant up to 3$^{\Delta}$; near esophoria up to 2$^{\Delta}$ and distant up to 1$^{\Delta}$); no hyper or hypofunctions of the ocular extrinsic muscles; near point of convergence (NPC) of ≤6.0cm, considered normal in this way[10]; stereoscopic acuity of 40″ of arc measured with a Titmus Stereo Fly.

We excluded patients with any history of eye surgery; reference to episodes of paretic, paralytic, or restrictive oculomotor alteration, or constant or intermittent eye deviations (heterotropies) in any look positions.

The prism bar (Gulden Ophthalmics, Elkins Park, PA, USA) used features of 15 prisms made of PMMA (acrylic) ranging from 2$^{\Delta}$ to 45$^{\Delta}$ (Figure 1), scaled as 2$^{\Delta}$, 4$^{\Delta}$, 6$^{\Delta}$, 8$^{\Delta}$, 10$^{\Delta}$, 12$^{\Delta}$, 14$^{\Delta}$, 16$^{\Delta}$, 18$^{\Delta}$, 20$^{\Delta}$, 25$^{\Delta}$, 30$^{\Delta}$, 35$^{\Delta}$, 40$^{\Delta}$, and 45$^{\Delta}$.

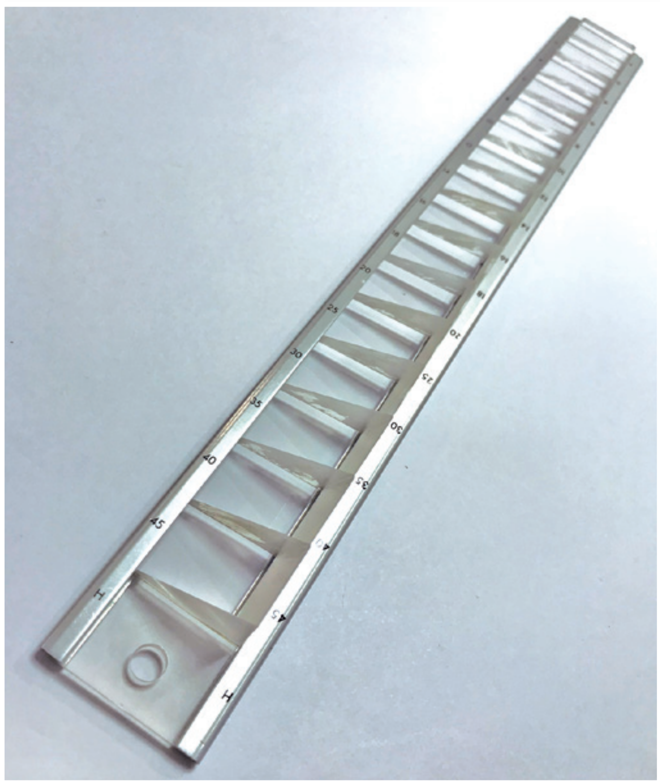


Figure 1. Illustration of the prism bar. The degree of optical displacement of the image of this bar varies from 2 to 45 prisms diopters, from the upper to lower prism.

The subjects were individually checked in an examination room equipped to perform an orthoptic evaluation after ophthalmic evaluation and prescription of spectacles if necessary, in the following order of examination:

1. Anamnese;
2. Distant and near visual acuity;
3. Verification of binocular positioning in the primary eye position, with measurements using cover test and prisms;
4. Binocular rotations;
5. Verification of the binocular positioning in all diagnostic positions with cover test and prisms;
6. NPC with properly positioned millimeter ruler and aiming with accommodative figure stimulus;
7. Stereotopic acuity with Titmus Stereo Fly.

Fusional amplitude measurements were obtained at a distance (5m) and near (33cm) of convergence and divergence using the prism bar, intentionally with an interposed sequence of convergence and divergence and never exceeding the maximum values previously established, as follows: distant convergence of 25^{Δ} and near convergence of 45^{Δ} as well as distant divergence of 8^{Δ} and near divergence of 14^{Δ}. In the measurements, 2 values were considered, the first being recorded as fusion break and the second as fusion restored and without additional stimuli, such as blinking or looking at a lower position, considering that stimuli (encouragement by the examiner) may overestimate convergence[11,12]; there is also the possibility of not breaking the fusion, indicated as without breaking (NBF).

In the measurements, we followed the following 4 sequences, interspersing convergence and divergence:

a) Distant Nasal (DN), distant temporal (DT), near nasal (NN), and near temporal (NT), with 11 patients in this group
b) NT, DN, DT, and NN, with 6 patients in this group
c) NN, NT, DN, and DT, with 11 patients
d) DT, NN, NT, and DN, with 7 patients in this group

It is important to note that a prism placed in front of one eye projects a second image shifted to the side of the base of this prism, causing diplopia. Thus, a nasal-based prism projects a second image nasally, forcing the patient to diverge to obtain a fusion of the images; hence, the divergence fusional amplitude is determined at the maximum prismatic value at which the patient was able to merge the diplopic images. Alternatively, a temporal-based prim projects a second image, temporally forcing the patient to converge to obtain a fusion of the diplopic images, resulting in the fusional amplitude of convergence.

RESULTS

The mean near fusional convergence was 45^{Δ}; however, 52.77% patients did not present fusion break (NBF) up to this value, and the remaining obtained mean refusion at 43.13^{Δ} (SD=2.4, median=45.0). The mean near fusional divergence was 14^{Δ}; however, 66.66% patients did not present fusion break (NBF) up to this value, and the remaining obtained mean refusion at 13.64^{Δ} (SD=0.8, median=14.0). The mean distant fusional convergence was 24.8^{Δ} (SD=0.8, median=25.0), with 44.44% patients without fusion break (NBF) up to this value, and the remaining with mean refusion at 21.6^{Δ} (SD=2.3, median=20.0). The mean distant fusional divergence was 7.9^{Δ} (SD=0.3,

median=8.0), and the remaining patients obtained mean refusion at 6.3$^{\Delta}$ (SD=0.7, median=6.0). Table 2 shows the values obtained in the evaluations.

There were no significant effects of age (p>0.05) or the sequence used (p>0.05). No significant correlations between age and fusional amplitude were found. Thus, as a first approach, normal fusional amplitudes measured with the prism bar are arranged in table 3.

Table 2. Mean values of the measured amplitude

	Near convergence	Near divergence	Far convergence	Far divergence
Without break-SQ (%)	0,527778	0,666667	0,444444	0
Mean break	45$^{\Delta}$	14$^{\Delta}$	24,85714$^{\Delta}$	7,942857$^{\Delta}$
Moda	45$^{\Delta}$	14$^{\Delta}$	25$^{\Delta}$	8$^{\Delta}$
Mean refusion	43,125$^{\Delta}$	13,63636$^{\Delta}$	21,57895$^{\Delta}$	6,342857$^{\Delta}$
Difference break/refusion	1,875$^{\Delta}$	0,363636$^{\Delta}$	3,421053$^{\Delta}$	1,657143$^{\Delta}$

Table 3. Proposed normative values

	Near (0,33m)	Far (5,0m)
Convergence	45$^{\Delta}$/40$^{\Delta}$	25$^{\Delta}$/20$^{\Delta}$
Divergence	14$^{\Delta}$/14$^{\Delta}$	8$^{\Delta}$/6$^{\Delta}$

DISCUSSION

A distant convergence ranging between 20$^{\Delta}$ and 25$^{\Delta}$, a near convergence ranging from 35$^{\Delta}$ to 45$^{\Delta}$, a distant divergence from 8$^{\Delta}$ to 6$^{\Delta}$, and a near divergence of 14$^{\Delta}$ are considered clinically normal if evaluated with a prism bar in most orthoptic clinics in Brazil. These values were determined through a quick and informal interview with Brazilian orthoptists and research data were not properly recorded, a fact that stimulated interest in determining normative values. Our study establishes normative values for convergence and divergence, both for breakage and refusion. With the establishment of these values and their respective uses, the diagnosis of amplitude and fusional stability may be more effective in clinical practice based on current scientific evidence.

Asthenopic symptoms, associated with binocular vision, may be associated with a reduction in the fusional amplitude, even before the appearance of other clinical signs such as a reduction of the near point convergence or difficult-to-control heterophoria or intermittent heterotropy. The normality values that we have established will be of great diagnostic and therapeutic support for these visual symptomatological conditions, which are increasingly frequent because of the use of electronic devices for near vision.

It is important to consider methodological differences related to fusional vergence measurements. Empirically, it is known that higher values of vergential amplitudes are also found when using the synoptophore because it allows a more gradual and slow modification between convergence and divergence values, even with the greatest natural dissociation caused by the artificiality of the stimuli used. Similarly, lower values are found when using isolated prisms and in intermediate uses with the prism bar because the removal and placement of prisms require extra oculomotor effort that negatively impacts amplitude measurements.

We chose the prism bar for our measurements because it has the advantage of greater portability than the synoptophore and is more practical to handle than a box of isolated prisms, besides avoiding extra efforts that imply increased variability in the measure owing to additional wear. By choice and limitation of the instrument used, it was decided not to verify the limits of the amplitudes, that is, not to go beyond the maximum values of the equipment, a fact that led us to consider the possibility of finding higher values than those found in this study. However, only considering the values we suggest as references present adherence to those used for years in practice by examining orthoptists, emphasizing that we must consider that the methodological limitation may have underestimated the values found by having previously established a ceiling for the measures.

According to the literature data for near convergence fusional amplitudes, measured with prism bar, Scheiman[11] found 19$^{\Delta}$ in children aged 6 years and 23$^{\Delta}$ in those aged 7–12 years, Chen[13] found 19.4$^{\Delta}$ in children aged 7–12 years, Wesson[14] reported 19$^{\Delta}$ in children aged 7–12 years, and Jimenez[15] found 18$^{\Delta}$ in children aged 6–12 years. The values found in the current study do not follow these data. The near divergence fusional amplitude values found in this study are corroborated by the literature mentioned because Scheiman[11] found 12$^{\Delta}$ in children aged

6 years and those aged 7–12 years. Chen[13] did not report corresponding values; Wesson [14] reported 13$^{\Delta}$ in children aged 7–12 years-old; and Jimenez[15] indicated 11$^{\Delta}$ in children aged 6–12 years.

Recently, Fray[12] established values evaluated with the prism bar that were close to those determined in this study. Fray found maximum values of near convergence fusional amplitudes of 35$^{\Delta}$, of near divergence fusional amplitudes of 16$^{\Delta}$, of distant convergence fusional amplitudes of 26$^{\Delta}$, and distant divergence fusional amplitudes of 7$^{\Delta}$.

In the most recent publication, a systematic review, in 2019[16], studies involving healthy individuals have shown that vergential amplitudes vary as follows: near convergence, the most referenced in the literature among the vergences, varied from 19$^{\Delta}$ to 57$^{\Delta}$; distant convergence ranged between 11$^{\Delta}$ and 33$^{\Delta}$; near divergence ranged from 8$^{\Delta}$ to 22$^{\Delta}$; and distant divergence from 5$^{\Delta}$ to 10$^{\Delta}$. Hence, our values are close to those found in recent research.

We should also consider that establishing a random sequence of convergence and divergence, albeit interspersed, may have underestimated the values, especially those of divergence because we know that the divergence assessed after convergence may have been influenced by the absence of complete dissipation of the inervational tonic stimulus applied during convergence measurement.

We conclude our work with the construction of normality values for the amplitude of near- and distant fusional measures that can guide more efficient diagnoses and therapeutic conducts because they will be conducted based on scientific evidence. The normative values are also updated and cover the range of population that uses mobile devices the most and has presented greater asthenopic visual complaints.

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